

## Assessment Strategy and General Methods

In 2003, the NCWAP released a Methods Manual that identified a general approach to conducting a watershed assessment, described or referenced methods for collecting and developing new watershed data, and provided a preliminary explanation of analytical methods for integrating interdisciplinary data to assess watershed conditions.

This chapter provides brief descriptions of data collection and analysis methods used by each of the program's participating departments, and an introduction to methods for analyzing data across departments and disciplines. While the information contained in the report is extensive, more detail is included in a set of appendices to this report from the following disciplines:

- California Department of Forestry
- Ecological Management Decision Support
- North Coast Regional Water Quality Control Board
- California Department of Fish and Game
- California Geologic Survey

The reader is referred to these appendices for more detail on methods, data analysis, and interpretation.

### Basin Assessment Approach

The steps in the large-scale assessment included:

**Form multi-disciplinary team.** In order to assess watershed conditions and processes, several specialists were needed and included: geologists, fluvial geomorphologists, foresters, water quality biologists, fisheries biologists, watershed habitat specialists, and planners;

**Conduct scoping and outreach workshops.** Landowner involvement was an important component in the assessment process. The Redwood Creek Assessment Team conducted two public meetings, starting with initial scoping and continuing through the public review of a draft report. These meetings included landowners, local agencies, local environmental groups, industry groups, watershed councils, and other interested parties;

During report preparation, the NCWAP team met and discussed issues with local experts from the Redwood Creek Land Owners Association (RNSP and Simpson, Barnum, and Sierra Pacific timber companies, and others). The public meetings and discussions were helpful to address the public's concerns, collecting data, and to gain insight into local watershed processes;

**Determine logical assessment scales.** The Redwood Creek assessment team used the California Watershed Map (CalWater version 2.2a) to delineate the Redwood Creek Basin into five subbasins (Estuary, Prairie Creek, Lower Redwood Creek, Middle Redwood Creek, and Upper Redwood Creek subbasins) for assessment and analyses purposes;

**Collect and organize existing data and information according to discipline.** The Redwood Creek basin is one of the most studied coastal watershed ecosystems in California. Numerous journal articles, technical reports and field studies of the basin's geology, fluvial geomorphology, hydrology, water quality and fishery resources have been produced by the U.S Geologic Survey, RNSP scientists, state resource agencies, private consultants, timber companies and HSU students. The NCWAP team performed an intensive search through the existing literature sources for information that would help describe past and present conditions throughout the basin. The vast amount of information provided by the literature reviews was both a virtue and overwhelming at times. Therefore two bibliographic lists are provided, a literature cited list and an additional reference literature list;

**Identify data gaps needed to develop the assessment.** Working with limited time and resources constrained the amount of fieldwork that was performed;

**Collect field data.** Over 50 miles of new stream data and numerous fishery surveys were performed for the assessment of the Redwood Creek basin. Water Quality data were analyzed from several locations in the basin that were provided for this assessment by private and agency cooperators;

**Amass and analyze information.** Each agency assembled, interpreted, and summarized data to create various specific reports for inclusion into the Assessment Report. Each agency's reports were also included in the Redwood Creek Basin appendices;

**Construct Integrated Analysis Tables (IA).** Through the synthesis of multidisciplinary studies and the use of IA Tables, the information from the various disciplines were integrated to help identify cumulative effects to watershed conditions and root causes to adverse changes to stream habitats.

**Conduct limiting factors analysis (LFA).** The Ecological Management Decision Support system (EMDS) was used, along with expert analysis and local input, to evaluate environmental factors at the tributary scale. These factors were rated to be either beneficial or restrictive to the well being of fisheries. The CDFG Restoration Manual (Flosi et al. 1998), and other literature, provided habitat condition values to help set EMDS reference curves;

**Conduct refugia rating analysis.** The assessment team created worksheets for rating refugia at the tributary scale. The worksheets have multiple condition factors rated on a sliding scale from high to low quality. Tributary ratings were determined by combining the results of air photo analyses, EMDS, Water Quality data, data in the CDFG tributary reports, and by a multi-disciplinary team of expert analysts. Ratings of various factors were combined to determine an overall refugia ratings on a scale from high to low quality. The tributary ratings were subsequently aggregated at the subbasin scale and expressed as a general estimate of subbasin refugia conditions. Factors with limited or missing data are noted and discussed in the comments section as needed. In most cases, there are data limitations on one to three factors. A discussion of the rating system is located at the end of this summary;

**Develop conclusions and recommendations.** Recommendation tables for watershed and stream improvement activities were developed at the tributary scale based upon stream inventory information, air photo analysis, field verification samples, workshop inputs, and other information. The recommendation tables are presented at the end of each Profile chapter as answers to the sixth assessment guiding question;

**Facilitate monitoring of conditions.** CDFG is developing a monitoring program and will facilitate it in the Redwood Creek and other assessed watersheds.

## Guiding Assessment Questions and Responses

The NCWAP assessment team developed lists of questions that they considered important to understanding and implementing watershed assessments. From those lists, a short list of guiding assessment questions evolved and was adopted to provide focus for the assessments and subsequent analyses, conclusions, and recommendations.

- What are the history and trends of the sizes, distribution, and relative health and diversity of salmonid populations within this?
- What are the current salmonid habitat conditions in this subbasin? How do these conditions compare to desired conditions?
- What are the impacts of geologic, vegetative, fluvial, and other natural processes on watershed and stream conditions?
- How has land use affected these natural processes?
- Based upon these conditions, trends, and relationships, are there elements that could be considered to be limiting factors for salmon and steelhead production?
- What habitat improvement activities would most likely lead toward more desirable conditions in a timely, cost effective manner?

These six questions focus the assessment procedures and data gathering within the individual disciplines and also provide direction for those areas of analyses that require more interagency, interdisciplinary syntheses, including the analysis of factors limiting anadromous salmonid production. The questions systematically progress from the relative status of the salmon and steelhead resource, to the focus of the assessment effort, and lastly to the watershed components encountered directly by the fish—flow, water quality, nutrients, and instream habitat elements, including free passage at all life stages. The products delivered to streams by watershed processes and the influence of human activities on those processes shape these habitat elements. The watershed processes and human influences determine what factors might be limiting fishery production and what can be done to make improvements for the streams and fish.

The first two assessment questions point out the importance of salmonid population information for validating the assessment and predicting habitat conditions. In many watersheds, robust population data may not be available, implying a need for future monitoring efforts. In some watersheds, a need for additional physical habitat sampling may be indicated.

The third and fourth assessment questions consider the past and present conditions of the watersheds and their natural and man-caused watershed processes. The answers to these questions provide us with insights into the future of assessed watersheds and streams, and the feasibility of different management techniques for salmon and steelhead in each watershed.

The last two assessment questions consider factors directly encountered by fish that could be limiting salmonid production. These questions seek to identify opportunities and locations for prudent management practices and pro-active salmonid habitat improvement activities.

These six guiding assessment questions are presented and answered in the overall basin section and in each of the subbasin sections of the assessment report. They are also considered in the CDFG Refugia Rating process at the subbasin and tributary scales. The responses become more specific as the assessment focuses from the course to the finer scales.

## Report Utility and Usage

This report is intended to be useful to landowners, watershed groups, agencies, and individuals to help guide restoration, land use, and management decisions. As noted above, the assessment operates on multiple scales ranging from the detailed and specific stream reach level to the very general basin level. Therefore, findings and recommendations also vary in specificity from being particular at the finer scales, and general at the basin scale.

A goal of this program is to help guide, and therefore accelerate the recovery process, by focusing stewardship and improvement activities where they will be most effective. Scaling down through finer levels guided by the recommendations should help accomplish this focus.

To do so, the report is constructed to help provide guidance for that focus of effort. A user can scale down from the general basin finding and recommendation concerning high sediment levels, for example, to the subbasin sections, to the stream reach level information to determine which streams in the subbasin may be most affected by sediment.

There is a list of surveyed streams in each subbasin section. In the general recommendation section, a tributary finding and recommendation summary table indicates the findings and recommendations for the surveyed streams within the subbasin. If indicated, field investigations at the stream reach or project site level can be conducted to make an informed decision on a land use project, or to design improvement activities.

## Program Products

The program will produce and make available to the public a set of products for each basin assessed.

These products include:

- A basin level Synthesis Report that includes:
  - Collection of Redwood Creek Basin historical information;

- Description of historic and current vegetation cover and change, land use, geology and, water quality, stream flow, water use, and instream habitat conditions;
- List of issues developed by agency team members and constituents;
- An interdisciplinary analysis of the suitability of stream reaches and the watershed for salmonid production and refugia areas;
- Tributary and watershed recommendations for management, refugia protection, and restoration activities to address limiting factors and improve conditions for salmonid productivity;
- Monitoring recommendations to improve the adaptive management efforts.
- Ecological Management Decision Support system (EMDS) models to help analyze data;
- Databases of information used and collected;
- A data catalogue and bibliography;
- Web based access to the Program's products: <http://ncwatershed.ca.gov/>, and <http://imaps.CDFG.ca.gov/>, and ArcIMS site.

## Assessment Report Conventions

### Subbasin Scale

The complexity of large basins makes it difficult to speak about them concerning watershed assessment and recommendation issues in other than very general terms. In order to be more specific and useful to planners, managers, and landowners, it is useful to subdivide the larger basin into smaller subbasin units whose size is determined by the commonality of many of the distinguishing traits. Variation in subbasins is a product of natural and human factors. Variables that can distinguish subbasins include differences in elevation, geology, soil types, aspect orientation, climate, vegetation, fauna, human population, land use, and other social-economic considerations.

For the purpose of the NCWAP study of Redwood Creek, the basin is divided into five subbasins (Figure II- 1). The five subbasins in Redwood Creek were designated based on geography, historical classification by Redwood National and State Park (RNSP), geology, climate patterns, and land use. They conform to CalWater 2.2 Planning Watershed boundaries when possible and 22 planning watersheds as defined by the CalWater 2.2 system. The Estuary Subbasin contains the area downstream of the confluence of Redwood and Prairie Creeks. Predominant features of the subbasin include the estuary, pasture lands, and the town of Orick.

### CalWater 2.2a Planning Watersheds

The California Watershed Map (CalWater Version 2.2a) is used to delineate planning watershed units (Figure II- 1). This hierarchy of watershed designations consists of six levels of increasing specificity: Hydrologic Region, Hydrologic Unit, Hydrologic Area, Hydrologic Sub-Area, Super Planning Watershed, and Planning Watershed (PW). CalWater version 2.2a is the third version of CalWater (after versions 1.2 and 2.0) and is a descendent of the 1:500,000-scale State Water Resources Control Board Basin Plan Maps drawn in the late 1970s.

The PW level of specificity is used in many analyses. PWs generally range from 3,000-10,000 acres in size and each PW consists of a specific watershed polygon, which is assigned a single unique code. The program used PWs for mapping, reporting, EMDS, and statistical analysis of geology, vegetation, land use, and fluvial geomorphology.

An important aspect of CalWater 2.2a PWs is that individual PWs often do not represent true watersheds. In other words, PWs often cut across streams and ridgelines and do not cover the true catchment of a stream or stream system. Streams, such as the mainstem Redwood Creek can flow through multiple PWs. In addition, a stream may serve as a border between two CalWater 2.2a PWs. This disconnect with hydrologic stream drainage systems is an artifact of the creation of CalWater 2.2a as a tool for managing forest lands in fairly consistent sized units.

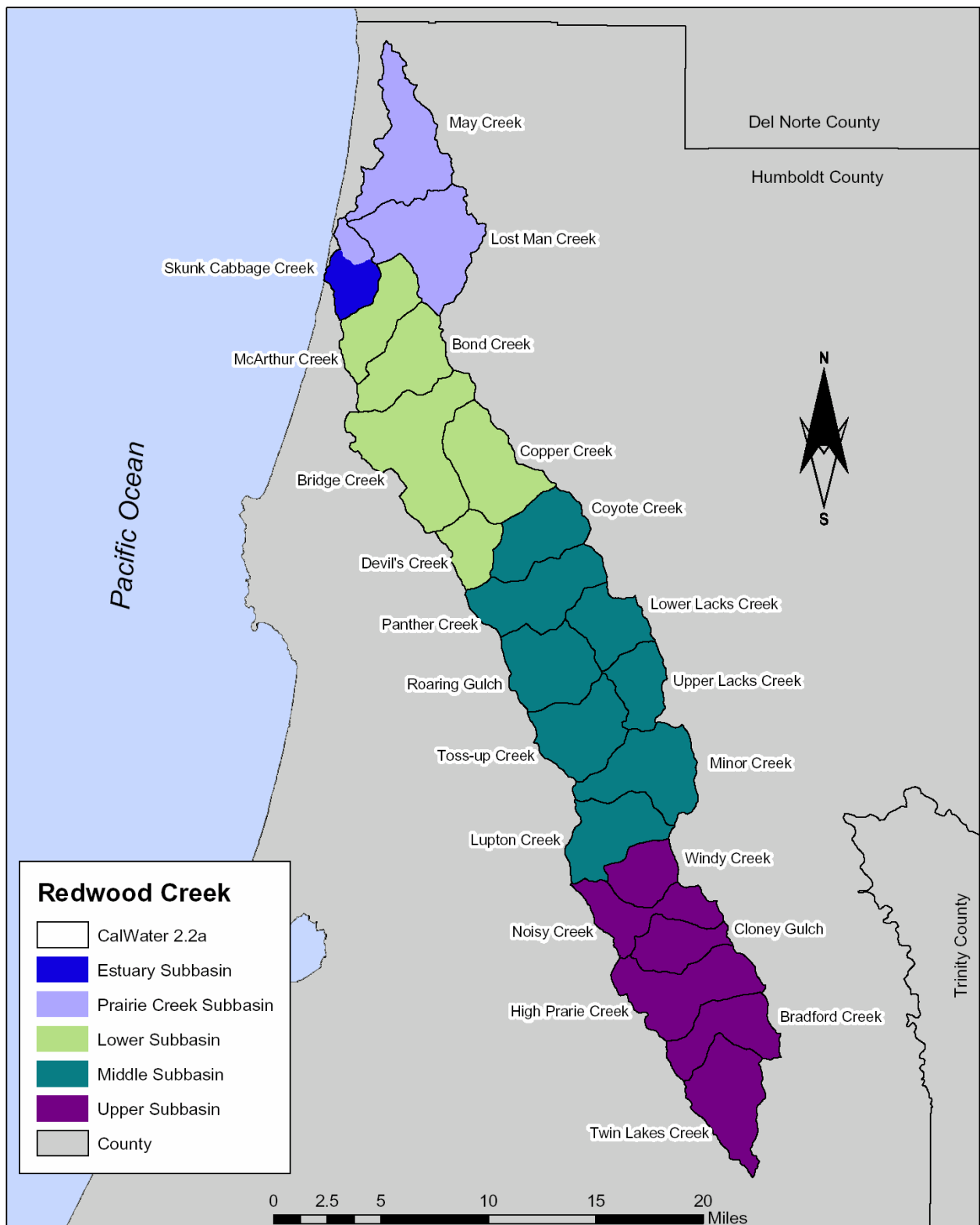


Figure II- 1. Redwood Creek Subbasins and Planning Watersheds.

## Hydrology Hierarchy

Watershed terminology often becomes confusing when discussing different scales of watersheds involved in planning and assessment activities. The conventions used in the Redwood Creek Basin assessment follow guidelines established by the Pacific Rivers Council. The descending order of scale is from *basin* level (e.g.,

Redwood Creek Basin)—*subbasin* level (e.g., Lower Subbasin)—*watershed* level (e.g., Prairie Creek)—*sub-watershed* level (e.g., Lost Man Creek).

The subbasin is the assessment and planning scale used in this report as a summary framework; subbasin findings and recommendations are based upon the more specific watershed and sub-watershed level findings. Therefore, there are usually exceptions at the finer scales to subbasin findings and recommendations. Thus, findings and recommendations at the subbasin level are somewhat more generalized than at the watershed and sub-watershed scales. In like manner, subbasin findings and recommendations are somewhat more specific than the even more generalized, larger scale basin level findings and recommendations that are based upon a group of subbasins.

The term watershed is used in both the generic sense, as to describe watershed conditions at any scale and as a particular term to describe the watershed scale introduced above, which contains, and is made up from multiple, smaller sub-watersheds. The watershed scale is often approximately 20-40 square miles in area; its sub-watersheds can be much smaller in area, but for our purposes contain at least one perennial, un-branched stream. Please be aware of this multiple usage of the term watershed, and consider the context of the term's usage to reduce confusion.

Another important watershed term is river mile (RM). River mile refers to a point that is a specific number of miles upstream from the mouth of a river. In this report, RM is used to locate points along Redwood Creek or tributary streams.

## Electronic Data Conventions

The program collected or created hundreds of data records for synthesis and analysis purposes and most of these data were either created in a spatial context or converted to a spatial format. Effective use of these data between the four remaining partner departments required establishing standards for data format, storage, management and dissemination. Early in the assessment process, we held a series of meetings designed to gain consensus on a common format for the often widely disparate data systems within each department. Our objective was to establish standards which could be used easily by each department, that were most useful and powerful for selected analysis, and would be most compatible with standards used by potential private and public sector stakeholders.

As a result, we agreed that spatial data used in the program and base information disseminated to the public through the program would be in the following format (see the data catalog at the end of this report for a complete description of data sources and scale):

**Data form:** standard database format usually associated with a Geographic Information System (GIS) shapefile or coverage (Environmental System Research Institute, Inc.® [ESRI]). Data were organized by watershed and distributed among watershed synthesis teams. Electronic images were retained in their current format.

**Spatial Data Projection:** spatial data were projected from their native format to Teale Albers, North American Datum (NAD) 1927 and Universal Transverse Mercator (UTM), Zone 10, NAD 1983. Both formats were used in data analysis and synthesis.

**Scale:** most data were created and analyzed at 1:24,000 scale to (1) match the minimum analysis scale for planning watersheds, and (2) coincide with base information (e.g., stream networks) on USGS quadrangle maps (used as Digital Raster Graphics [DRG]).

**Data Sources:** data were obtained from a variety of sources including spatial data libraries with partner departments or were created by manually digitizing from 1:24,000 DRG.

Spatial data sets that formed the foundation of most analysis included the 1:24,000 hydrography and the 10 meter scale Digital Elevation Models (DEM). Hydrography data were created by manually digitizing from a series of 1:24,000 DRG then attributing with direction, routing, and distance information using a dynamic segmentation process (for more information, please see <http://arconline.esri.com/arconline/whitepapers/ao/ArcGIS8.1.pdf>). The resulting routed hydrography allowed

for precise alignment and display of stream habitat data and other information along the stream network. The DEM was created from base contour data obtained from the USGS for the entire study region.

Source spatial data were often clipped to watershed, planning watershed, and subbasin units prior to use in analysis. Analysis often included creation of summary tables, tabulating areas, intersecting data based on selected attributes, or creation of derivative data based on analytical criteria. For more information regarding the approach to analysis and basis for selected analytical methods, see Chapter 2, Assessment Strategy and General Methods, and Chapter 4, Interdisciplinary Synthesis and Findings.

## Methods by Department

This section provides methods used for this report. Additional information on methods may be found in the NCWAP Methods Manual posted at the NCWAP web site ([ncwatershed.ca.gov](http://ncwatershed.ca.gov)).

### Geology and Fluvial Geomorphology

CGS developed the paper and digital geologic maps that accompany this report using a variety of information. Redwood National Park (RNSP) converted earlier mapping at a scale of 1:62,500 by Harden and others (1982) into a digital product for their in-house use in 2001. RNP finalized the map in late 2001 for use in this program. CGS converted additional unpublished mapping for the Prairie Creek portion of the watershed by Kelsey (written communication, 2001) into digital coverages. CGS merged most of the bedrock geology, faults, and other structural information from these sources to create a continuous geologic base map for the entire watershed. It should be noted that although the bedrock geology presented in this map series is at a scale of 1:24,000, the detail and accuracy is limited to the resolution of the original products. CGS performed very limited field checking of the final product because of time constraints.

The original mapped landslides, alluvium, and river terrace deposits were deleted or modified and replaced with more detailed landslide and fluvial coverages developed during this study. CGS geologists based the new coverages on detailed aerial photograph interpretation using historical aerial photographs dating back to 1947. Please refer to the CGS appendix report for detailed information regarding the specific coverages. In addition to the paper map products presented with this report, the GIS database is available as ArcInfo coverages through both NCWAP ([www.ncwatershed.ca.gov](http://www.ncwatershed.ca.gov)) and CGS. Separate and multiple GIS layers were created for the geologic, landslide-related and fluvial geomorphic assessments. Each feature recorded in the landslide and fluvial layers was assigned numerous attributes, based on a pre-established method of assessment. Please refer to the CGS Appendix E plates 1 through 3 entitled Geologic and Geomorphic Features Related to Landsliding and report text for detailed information regarding the specific coverages.

CGS evaluated mass wasting in all modes of movement as a function of geologic unit and slope inclination when the final maps were completed. The analysis was performed to show the typical slope within mapped landslides in most of the units in the watershed because of time constraints. Geologic units appearing to have similar characteristics based on aerial photograph interpretation were grouped together for clarity. The data sets consisted of the mapped landslides, bedrock geology, and the 10-meter digital elevation model (DEM) for the watershed. These evaluations provide a means of generally assessing the relative rock strength and texture of individual units in the absence of formal geotechnical data. Data from this analysis contributed to the ranking of bedrock units during the development of our relative stability map.

The Relative Stability Map used a decision matrix developed and fine-tuned by CGS geologists familiar with the study area. The bedrock and landslide units were merged with a digital grid coverage for the entire watershed. The relative stability of individual cells was determined based on bedrock unit (see Figure III-8), landslide type and activity, and other geomorphic features as a function of slope depending on their location. The higher ranking was used on the map when a cell received two potential values (e.g.: a bedrock ranking and landslide ranking). CGS converted the grid coverage of relative landslide potential into a polygon coverage and generated the final relative stability maps (Plates 4 through 6, Relative Landslide Potential with Geologic and Geomorphic Features, CGS appendix) at a scale of 1:24,000 to match that of the Geologic and Geomorphic Features Map.

## Fluvial methods

We created maps of the fluvial geomorphology for all streams in the Redwood Creek watershed designated by blue lines on published USGS 1:24,000-scale topographic quadrangle maps. Some additional watercourses were also mapped if they could be observed at the photo scale. We mapped fluvial features from 1:31,680-scale aerial photographs taken during 1984 and 1:24,000-scale photos taken during 2000. The 1984 photos provided a view of the watershed after a particularly wet water year, while the 2000 photos provided "existing" conditions. In 1983, annual runoff at Orick was 1,191,000 acre feet and annual runoff at Highway 299 - O'Kane (Blue Lake) was 284,900 acre feet, both of which were exceptionally high rates (See Appendix G, Department of Water Resources Report, this report). The air photos taken in 2000 were the most recent photos available.

We developed criteria to distinguish channel-disturbance features from natural sediment channel storage for reconnaissance study using small-scale aerial photographs. Features indicating channel disturbance include lateral, mid-channel, transverse and junction bars, wide and braided channels, aggrading and degrading reaches, tributary fans and eroding banks and exclude more stable features such as point bars and vegetated bars.

Every fluvial Mylar layer for each quadrangle and interpretation year was digitally scanned at a resolution of 400 dpi (dots-per-inch) or finer following compilation. Scanned mylars were then geo-referenced to the UTM-Zone 10, NAD 83 projection so that they could be digitized on the computer screen. Geo-referenced images were converted to ArcView grid files to allow for the background to be made transparent. On-screen digitizing was done by each project geologist or GIS specialists using ArcView 3.2 or ArcInfo 8.1 software. Digitized features were attributed (the database table, called a \*.dbf file) was filled with information by the project geologist using ArcView 3.2 software and an ArcView Avenue extension created by CGS GIS staff specifically for NCWAP fluvial and landslide data entry. Final digital map products were produced both as ArcView shape files and ArcInfo coverages.

The design of the databases attached to the stream features layers were identical except that the planimetric unit field types differed by feature type (polygon, line, or point). The geologist could enter a primary channel characteristic attribute and as many as three additional secondary attributes for each mapped stream feature. Stream characteristic attributes were selected from a checklist of 32 channel features. Some of these features are indicative of channel instability (e.g., eroding banks), sediment storage (e.g., mid-channel bars) and other general channel attributes such as presence of pools or riffles. Channel characteristics were entered in order of importance. The primary characteristic field was used by the NCWAP Watershed EMDS to identify whether the feature represented channel instability or elevated sediment storage.

Following development of the ArcView shape files, the alluvial layer was used along with the geology and landslide layers to make maps the maps as follows: Plate 1, Sheets 1-3, Watershed Mapping Series, Map of Redwood Creek Watershed, Humboldt County, Geologic and Geomorphic Features Related to Landsliding and Plate 2, Sheets 1-3, Watershed Mapping Series, Map of Redwood Creek Watershed, Humboldt County, Relative Landslide Potential with Geologic and Geomorphic Features. The fluvial layers were analyzed in ArcView GIS with geology layers to evaluate relationships between landslides and negative stream characteristics and to estimate changes in channel characteristics between 1984 and the present. The alluvial contacts overlay was utilized in both the geology map and the landslide potential map, replacing previous alluvial contacts taken from the literature. The alluvial contact was mapped with input from Redwood National and State Parks (RNSP). However, alluvial contacts were terminated in channels where the alluvial valley width was less than 100 ft because of map scale constraints.

While mapping fluvial features from 1984 and 2000 aerial photographs, our fluvial staff mapped streamside landslides. We compiled these into a spatial database as points, without regard to the size and analyzed the number of small active landslides per acre and pre stream length. Results were compared between planning watersheds as described below.

We carried out a broad-level description of major stream types based on the Rosgen method of stream classification (Rosgen, 1996). This method provides a general physical characterization of stream channels for coarse assessment of the watershed. Stream gradients were generated from USGS topographic data. We assigned Rosgen channel types based on stream gradient and study of aerial photographs.

CDFG field crews trained in Rosgen techniques measured cross sections in Redwood Creek and some of its tributaries in 2001 for habitat typing surveys. The field crews identified channel type and measured channel cross sections at appropriate locations in the channel. They measured bankfull width by stretching a level tape from one bank to the other, perpendicular to the stream. Bankfull level was identified from changes in substrate composition, bank slope and perennial vegetation—all caused by frequent scouring events. The crews measured cross sections along a taut horizontal tapeline, starting at an assumed bankfull point and recording bankfull depth from the surface of the substrate to the level of the tape at 10 equally spaced stations to the bankfull point on the opposite bank. CDFG field crews measured channel gradients along steeper sections where channels appeared to be Rosgen types A or A+.

## Hydrology

The role of the Department of Water Resources (DWR) in the NCWAP is to provide new stream flow data, compile historic stream flow data, and assist in compiling water rights information. Historical stream flow and water rights data are compiled from existing DWR, State Water Resources Board, and US Geological Survey information. Current water rights information is compiled from DWR and State Water Resources Board files.

A search of the SWRCBs Water Right Information System (WRIMS) was performed to determine the number and types of water rights within the Redwood Creek watershed. The WRIMS database is under development and may not contain all post-1914 appropriative water right applications that are on file with the SWRCB at this time. Some pre-1914 and riparian water rights are also contained in the WRIMS database for those water rights whose users have filed a “Statement of Water Diversion and Use.” A location map of the point of diversion is shown in Section III, Figure III-7.

## Vegetation and Land Use

The California Department of Forestry and Fire Protection (CDF) performed analysis of vegetation, land use and fire hazard assessment.

Analysis of vegetation in the Redwood basin was performed with use of the California Land Cover Mapping and Monitoring Program which can be viewed at [http://www.frap.cdf.ca.gov/projects/land\\_cover/index.html](http://www.frap.cdf.ca.gov/projects/land_cover/index.html). Stream buffer analysis was conducted to assess the amount of vegetation cover found along the watercourses within Redwood Creek as a whole. The data used for this analysis were the vegetation data, discussed above, plus a 1:24,000 stream coverage developed by CDF from the USGS digital line graphs. Three different zones based upon different buffer widths were assessed. First a 50-foot buffer (i.e., going out 50 feet from each side of the stream) was used to assess what the minimum conditions may be based on the old Forest Practice Rules. The second buffer width used was a 150-foot zone to represent the current Forest Practice Rules for the protection of a fish-bearing stream. The final zone was a 90-meter (300 feet) buffer based upon the approach taken in the Northwest Forest Plan.

Additional vegetation assessment was completed for the stream reach information collected by the Department of Fish and Game. Digital vegetation information was utilized to determine the area and vegetation type, size class, and canopy density for the 66 separate fish bearing stream reaches (located mostly in the Middle Subbasin) surveyed by CDFG (Table II-19). A buffer zone of 150 feet along each side of the stream reach was developed to determine specific vegetation information. The 150-foot buffer zone was used because it corresponds to the required watercourse and lake protection zones (WLPZ) outlined in the current Forest Practice Rules. This buffer width would closely resemble the buffer width required for fish bearing streams under the current Forest Practice Rules. The vegetation information was obtained from the CALVEG types. The minimum mapping size is 2.5 acres for contrasting vegetation types. The vegetation layers were then “clipped” to the GIS shape files for the stream reach assessment. Acres of cover type, percent canopy closure, and tree diameter class were then calculated utilizing ArcView GIS.

Assessment of timber harvesting history was completed with the use of aerial photographs. Various photo flights from different available years were employed. Starting with the year 1942, which was the earliest flight readily available, photo flights for 1942, 1948, 1952, 1954, 1958, 1964 and 1977 were utilized to determine past harvest areas. For the decades of the 1980s and 1990s actual timber harvest plans were utilized along with

satellite multi-spectral scanned image data (MSS). This MSS data was used to indicate changes in the vegetation and not just timber harvesting.

In order to assess fire hazard in Redwood Creek and its potential threats to salmonid habitat, CDF used data and approaches developed as part of the CDF Fire Plan that can be found at (<http://www.fire.ca.gov/FireEmergencyResponse/FirePlan/FirePlan.asp>). “Fire hazard” refers to the degree of flammability of the fuels once a fire starts, including the fuel (type, arrangement, volume, and condition), topography and weather. Fire hazard was assessed using data that predict potential fire behavior of the flaming front (i.e., rate of spread, flame length, tree torching, etc.) under typical severe fire weather.

Specifically, this process involves mapping fuel conditions and slope features, applying a standardized fuel moisture and wind profile to predict surface fire behavior, then ranking the resultant behavior index into moderate, high, and very high categories. For forested areas, these surface fuel rankings were then subjected to an additional assessment of ladder fuel (fuels that are relatively continuous vertically from the ground surface upwards so as to facilitate the movement of surface fire up into the tree canopy) and crown fuel characteristics where the surface fuel ranking did not fully capture the expected fire hazard present (i.e., where aerial fuel structure would likely lead to torching of trees and crown fire). Areas not supporting wildland vegetation and unlikely to sustain fire (e.g., agricultural areas) were classified as “not mapped.” A detailed discussion of the methodology for ranking fuels can be found on the Internet at [http://frap.cdf.ca.gov/data/fire\\_data/fuel\\_rank/index.html](http://frap.cdf.ca.gov/data/fire_data/fuel_rank/index.html).

A moderate fuel ranking for an area indicates that, should a fire ignition occur, flame lengths would likely be low enough for direct attack at the flaming edge by hand crews, and rates of spread slow enough for containment with initial attack at very small sizes. Fire effects in the moderate threat class would likely be of low severity, causing little vegetation mortality except to annual grasses and forbs that will reseed in the year following the fire. A high fuel ranking is interpreted as indicating that an ignition will lead to fire behavior exhibiting relatively intense fires, with flame lengths typically between 4 and 8 feet, and rates of spread indicating moderate chance of escape from initial attack depending on location of fire. Severity of fires occurring in the high fuel rank areas would likely result in mixed levels of vegetation mortality, with smaller trees and more sensitive species dominating the mortality distribution. Finally, a very high fuel ranking indicates that fires are likely to be intense, with surface flame lengths in excess of 8 feet, and moderate to high levels of crown fire. Severity of fire effects on dominant vegetation would likely be high, with widespread mortality, and a potentially stand-destroying fire killing even large, fire-resistant vegetation.

## **Water Quality**

### ***RWQCB Data Sources***

The Regional Water Board compiled and evaluated existing data and collected new water quality data. The data analysis in this water quality assessment includes basic water chemistry, water temperature, sediment, and biological parameters. Although the data gathering, data collection, and data analysis techniques are explained in the subsequent sections, more detail can be found in the NCWAP methods manual (California Resources Agency 2001).

All the gathered raw data used in this assessment has been compiled and integrated into the KRIS Redwood Creek database for future access by interested parties.

### ***Data Gathering***

Data gathering is the process of compiling existing data from Regional Water Board files, other agency files, and other sources (such as landowners in the watershed). The Regional Water Board has several types of water quality information available within the organization, including Timber Harvest Plan (THP) files, water quality monitoring files, Total Maximum Daily Load (TMDL) files, grant files, environmental impact reports, and other documents. All of the available internal water quality information was evaluated for inclusion into this assessment. Sources outside the office included data and reports from other agencies, US EPAs StoRet water quality database, watershed groups, landowners, and public interest groups. As data are gathered, the location and general characteristics of the data were catalogued in a database regardless of if it was directly applicable to

the Regional Water Board portion of the watershed assessment. This was done to track internal data and also to provide a record of the data that were reviewed. All the catalogued data were made available to the other NCWAP agencies for theirs and the public's use.

### **Landowners**

Data were provided by several landowners of the Redwood Creek watershed for this watershed assessment. This included water temperature and sediment information from the Redwood National and State Parks (RNSP) and numerous references containing data from studies conducted in the Redwood Creek watershed from the Redwood Creek Landowners Association.

In the case of Simpson Timber Company, summary water temperature data was taken directly from Timber Harvest Plans because the company did not wish to share raw data or collection protocols.

### **Forest Science Project (FSP)**

FSP was actively compiling and analyzing water temperature data in the North Coast area from 1990 to 1998. During one or more years over this time period, the major landowners in the Redwood Creek watershed contributed water temperature data to the project. This included Redwood National and State Parks (RNSP), Simpson Timber Company, Barnum Timber Company, and other private landowners.

In most cases, the data from FSP was used for this assessment. However, additional temperature data taken after 1998 was incorporated into the assessment from RNSP.

### **North Coast Regional Water Quality Control Board (Regional Water Board)**

Various water quality samples were collected at one site on the mainstem of Redwood Creek between 1959 and 1988. This data is available at the Regional Water Board office and also in US EPA's Legacy StoRet database, which is available on the US EPA website.

The Regional Water Board collected water quality samples at one site in the Redwood Creek watershed from 2001-03. A total of thirteen samples were collected under the SWAMP program and used for this assessment. Regional Water Board water quality monitoring sites are shown in Water Chemistry Map 1.

### **United States Environmental Protection Agency (US EPA)**

While the US EPA did not collect any original data in Redwood Creek, it made data from USGS and the Regional Water Board available through its Legacy StoRet database. This is available on the US EPA's website and includes all of the data collected by USGS and the Regional Water Board at two closely located sites, named Redwood Creek at Orick. For the purposes of this assessment, these sites are treated as one site because they are in close proximity to one another. It is believed that this will have a negligible effect on this assessment of water chemistry.

### **United States Geological Survey (USGS)**

Various water quality samples were collected at 40 sites throughout the Redwood Creek watershed between 1973 and 1977. This data now resides in the USGS sample database and also the StoRet database, both of which are available at the respective agencies' website.

### **Watershed Groups**

Watershed groups active in Redwood Creek include the Pacific Coast Fish, Wildlife, and Wetlands Restoration Association and the Redwood Community Action Agency. At the time of publication, no data were made available to the Regional Water Quality Control Board from these or any other watershed group.

### **Data Collection**

Regional Water Board staff collected water quality measurements thirteen times during 2001-03 in Redwood Creek. This sample collection and analysis was done under the Surface Water Ambient Monitoring Program (SWAMP). Sample collection and analysis was in accordance with methods used by the USGS and the US

EPA. Those methods are explained and referenced in the NCWAP Methods Manual (CRA 2001). While in the field, staff recorded basic “point in time” water chemistry data including pH, specific conductance, temperature, turbidity, and dissolved oxygen. Grab water samples were also collected then analyzed by an independent, certified laboratory for chlorophyll-a, alkalinity, hardness, organic and inorganic compounds, metals, and mercury. While staff hoped to collect stream channel information, such as pebble counts, we were unable to accomplish this due to access and resource constraints. However, a joint monitoring effort with the RNSP resulted in the donation of two temperature recorders for monitoring water and air temperature.

### **Summary of Assessment Process**

The assessment process involves four basic steps, as outlined below:

- **Collection and gathering of water quality data and other pertinent information.** This involves collection of new data, gathering existing data internally or from other agencies, landowners, etc. In some cases, there may be related information that is not numeric, but useful to the assessment process. This is discussed in further detail in the Data Gathering section.
- **Compile and assess data based on the data quality.** Once the new data have been collected and the existing data have been gathered, all of the data are compiled to prepare it for analysis. Each of the references reviewed is cataloged in a database and raw and summary data are compiled into spreadsheets or some other electronic file appropriate for the data type. At this point, the data are also reviewed for data quality to determine the level of confidence in the data for use in the assessment. The data are then analyzed and compared to various criteria that have been established. This is discussed in further detail in the Criteria Used for this Assessment, the Data Analysis, and the Limitations and Data Quality sections.
- **Form hypotheses based on the water quality data.** Where possible, hypotheses are drawn on stream conditions based primarily on the water quality analysis. This is discussed in further detail in the Data Analysis Methods section and in general in the Overall Conclusions and Subbasin sections.
- **Confirm/refute hypotheses during the synthesis process with data from other NCWAP team members and draft the synthesis report.** Once the individual water quality assessment report has been drafted and preliminary hypotheses have been formed, each of the NCWAP agencies met to create a “synthesis report.” During synthesis discussions, the hypotheses were tested against the data and findings from the other agencies to provide additional evidence to either support or detract from the hypotheses. At this point, each of the agencies combined the knowledge and data into a single comprehensive synthesis report covering all of the disciplines brought to the table by the NCWAP agencies. The discipline specific report and the combined synthesis report was then reviewed internally until a draft was released for public review and comment.

Past and current water quality data were evaluated regarding compliance with water quality objectives in the North Coast Regional Water Quality Control Board’s (NCRWQCB) Basin Plan. Those same water quality data, as well as sediment and habitat data, were evaluated against TMDL targets for Redwood Creek and data dependency relationships (ranges and thresholds) for the knowledge-based EMDS evaluation model, described in a subsequent section. The specific water quality thresholds and ranges (objectives, TMDL targets, EMDS ranges and thresholds) are shown in Table II- 1 and are detailed in the Appendix C.

Two metrics were used to evaluate summer water temperature suitability for salmonids of Redwood Creek. The first metric is the maximum weekly average temperature (MWAT), which is the upper temperature recommended for a species life stage or a threshold that should not be exceeded over any seven-day period (Armour 1991). The second metric is the seasonal maximum or the highest temperature observed during the hottest part of the year.

The MWAT is determined from data collected by continuous data recorders placed in the stream during the warmest part of the year, usually the months of June through October. An MWAT of 63°F or less is considered suitable for most anadromous fish production (Brett 1952, Reiser and Bjorn 1979). Coho salmon and coastal cutthroat trout are considered the most temperature sensitive species. Welsh et al. (2001) found in the Mattole basin that no streams with an MWAT greater than 62.5°F contained coho salmon. In addition, all of the streams where the MWAT was less than 58°F contained juvenile coho salmon. Hines and Ambrose (Draft, 2000)

suggest that “the number of days a site exceeded an MWAT of 63.7°F (17.6°C) was one of the most influential variable predicting coho salmon presence and absence”. “If a simple threshold were to be considered best, it would be 63.7°F (17.6°C)” (Hines and Ambrose Draft, 2000). The number of days above suitable temperature conditions were not examined in this assessment due to time constraints and uncertainty of how many days above the MWAT will adversely affect salmonids. However, the data are available through the KRIS Redwood database for future suitability assessments. Future study of time related impacts of temperature exposure should be conducted to more accurately assess the threat of high water temperatures to salmonid production.

*Table II- 1 Criteria Used in the Assessment of Water Quality Data.*

<b>Water Quality Parameter</b>	<b>Range or Threshold Protective of Bus<sup>1</sup>, Including Cold Water Fish Species</b>	<b>Source of Range or Threshold</b>
PH	6.5-8.5	Basin Plan, p 3-3.00
Dissolved Oxygen	7.0 mg/L	Basin Plan, p 3-3.00
Temperature	No alteration that affects BUs 1 No increase above natural > 5°F 50-60°F MWAT <sup>2</sup> – Fully suitable 61-62°F MWAT – Moderately suitable 63°F MWAT – Somewhat suitable 64°F MWAT – Undetermined 65°F MWAT – Somewhat unsuitable 66-67°F MWAT – Moderately unsuitable ≥68°F MWAT – Fully unsuitable 75°F daily max (lethal)	Basin Plan, p 3-3.00 Basin Plan, p 3-4.00  Cold water fish rearing, RWQCB (2000), p. 37
Specific Conductance	<90% of upper limit at 220umhos <50% of upper limit at 145umhos	Basin Plan, p 3-6.00
Nutrients (Biostimulatory Substances)	No increase in concentrations that promote growths and cause nuisance or adversely affect beneficial uses	Basin Plan, p 3-3.00
Mean particle size diameter (D50) from riffle crest surfaces	>37mm (single minimum for a reach) >69mm (mean for a reach)	Redwood Creek TMDL, EPA (1998)
Percent fines <0.85 mm	<14% in fish-bearing streams <sup>4</sup>	Redwood Creek TMDL, EPA (1998) EMDS <sup>3</sup> Fully Suitable
Percent fines <6.5 mm	<30% in fish-bearing streams	Redwood Creek TMDL, EPA (1998) EMDS Fully Suitable

<sup>1</sup> BUs = Basin Plan beneficial uses

<sup>2</sup> MWAT= maximum average weekly temperature, to be compared to a 7-day moving average of daily average temperature

<sup>3</sup> EMDS = Ecological Management Decision Support model used as a tool in the fisheries limiting factors analysis. These ranges and thresholds were derived from the literature and agreed upon by a panel of NCWAP experts.

<sup>4</sup> fish-bearing streams = streams with cold water fish species

To evaluate temperature data with respect to salmonid populations, specific criteria had to be developed to rate habitat conditions. The NCWAP Team developed MWAT ranges for the EMDS model as an average of the needs of several cold water fish species (note that we were unable to actually use this portion of the EMDS model due to an inadequate amount of MWAT data). All temperature data were compared to this EMDS suitability range.

The MWAT breakdowns for EMDS are as follows:

- Fully suitable = 50-60°F (10-15.6°C)
- Moderately suitable = 61-62°F
- Somewhat suitable = 63°F
- Undetermined (between somewhat suitable and somewhat unsuitable) = 64°F
- Somewhat unsuitable = 65°F
- Moderately unsuitable = 66-67°F
- Fully unsuitable = ≥68°F

Seasonal maximum or peak temperature data speak to the threat of harm from temporary or short-term exposure to extreme conditions. It is generally accepted that a threshold temperature exists that fish can withstand for short consecutive period of hours before damage is caused by stress (Armour 1991). The instantaneous seasonal maximum that may lead to salmonid lethality is  $>75^{\circ}\text{F}$  (RWQCB 2000). This is the EMDS suitability criterion for seasonal maximum temperatures.

Existing data for percent of fine subsurface material in the  $<0.85$  and  $<6.5\text{mm}$  fractions are comparable to numeric TMDL targets derived from sampling methods which include core samples from a McNeil type sampler sieved wet, with fines measured by volumetric displacement. See Valentine (1995) for a description of the McNeil sampling and analysis method. A discrepancy exists between the requirements of the US EPA approved TMDL for Redwood Creek and the Technical Support Document written by the NCRWQCB, on which the US EPA TMDL was based. The US EPA document states that subsurface sediment samples should be sieved dry, however the numeric targets derived in the Technical Support Document were based on the wet sieved method and volumetric displacement. The percent of fine materials in subsurface sediment samples sieved wet are not comparable to samples that are dried and measured gravimetrically, unless a conversion factor is empirically derived from the geologic formation through which the stream flows. The discrepancy between the two analysis methods has yet to be resolved between the two agencies. Consequently, streambed sediment data analyzed gravimetrically are not comparable to existing TMDL targets. These data were not discussed in this assessment but are included in Appendix C.

### **CDFG Anadromous Salmonid Populations and Stream Habitat Assessment**

The California Department of Fish and Game's (CDFGs) role in the Redwood Creek watershed assessment involved working with local scientists and an extensive review of numerous reports describing historic and current salmonid populations and watershed conditions. The stream habitat assessment process depended largely on results from stream habitat surveys conducted by CDFG crews during 2001. Goals of the assessment include:

- Assess past and present status of anadromous salmonid populations;
- Assess anadromous salmonid habitat conditions;
- Identify potential limiting factors to anadromous salmonid production;
- Identify and characterize salmonid refugia habitat;
- Develop recommendations for salmonid habitat improvement projects.

### **Stream Surveys**

Surveys of physical habitat conditions were conducted in the Redwood Creek basin June through September 2001. Stream surveys were performed in the Middle and Upper subbasins on approximately 27.5 miles of mainstem Redwood Creek and approximately 21 miles within 18 tributary streams. In addition, a set of randomly selected stream reaches were sampled in the Prairie Creek and Lower Redwood Creek subbasins. Stream survey and sample reach data collection used physical habitat and biological data collection protocols presented in the *California Salmonid Stream Habitat Restoration Manual* (Flosi et al. 1998). Streams were surveyed until the end of anadromy was determined. Crews based this judgment on either physical barriers to fish passage or steep gradient (8-10% for  $>1,000$  ft.) present for long continuous stretches of the creek. The crews also made visual observations for fish presence above suspected barriers to help determine the end of an anadromous fish bearing reach.

Electrofishing was used to determine presence and distribution of salmonid species. CDFG fish biologists equipped with Smith Root Model 12 backpack electrofishing units performed the fish data collection. They sampled at least one pool, run and riffle per reach. Mainstem Redwood Creek was sampled only at a few sites due to the depths of pools that reduce the effectiveness of the electrofishing units and capture efficiency. Collected specimens were identified to species and age class (estimated based on size) and released. Non-salmonid species were also recorded but not classified by age class. Electrofishing was also part of the state

wide coho distribution survey. Presence/absence Electrofishing Protocol for anadromous salmonids used in summer 2001 is presented below.

**Objective:** Identify the presence of anadromous salmonids and species composition within each stream survey reach using the following protocol:

- Electrofishing is conducted following completion of stream habitat and channel inventories for each creek;
- Stream reaches are designated based upon measurements recorded by surveyors using Rosgen channel type criteria;
- Electrofish sampling is conducted within each reach of the stream and above the end of anadromy (when possible). Sampling begins just upstream of the stream's mouth (out of the area of influence of the receiving stream or river) and continues upstream following methodology described below:
  - A total of 10 pools per reach are electrofished to determine if juvenile;
  - Anadromous fish are present. The pools are to be distributed throughout the length of the stream reach to be sampled. At least two electrofishing passes are made in each pool unit sampled. After the capture at least one specimen of each potential species, sampling in that reach is terminated and the surveyors move onto the next reach to continue sampling. The same protocol was used for each reach unless:
    - ◊ The reach is short (less than  $\frac{1}{4}$  mile), approximately five pools should be sampled;
    - ◊ There are several reaches present (e.g. more than 3 or 4) or time is an issue, then as many reaches as possible should be sampled in an upstream direction;
    - ◊ Access is not possible throughout the stream reach, then the above protocol should be applied to that portion which accessible.
- Approximately five pool, riffle, or run habitats should be sampled upstream of the suspected end of anadromy;
- Pools selected for sampling are pools where one would expect to find coho salmon, i.e. those with habitat complexity. If complex pools are not present after passing several pools, then the common pool type found within that section of stream are sampled;
- Fish captured were identified by species and then counted and categorized into young-of-the-year, one-plus, or two-plus age classes.

### **Sample Reaches**

The CDFG in cooperation with the Corvallis, Oregon, EPA Field Station randomly selected sampling reaches located in the Prairie Creek and Lower subbasins. The reaches were selected using an unequal probability random tessellation stratified (RTS) survey design with an oversample (Stevens 1997, Olsen 2000). The RTS method was used for its ability to select a spatially balanced set of sampling points across the study area. Stevens and Olsen (1999) describe the RTS design applied to streams.

A base map of the Lower and Prairie Creek subbasins showing the stream network and limits of winter steelhead distribution served as the sampling frame. The RTS generated a set of GPS coordinated points (20 primary sites and 40 oversamples) on the fish bearing streams. Twenty primary sites were selected based on the limited amount of time (7 days) and staff available to conduct the sample surveys. Maps were made showing the approximate location of the sampling points. Crews equipped with GPS units then located the points as near as possible to the stream. Once a point was located, the length of the sampling reach was determined. A sample reach length was either 20 bankfull widths or a minimum length of 500 feet and a maximum length of 1500 feet (Gallo 2000). Average bankfull width was determined nearest the central location of the GPS coordinates identifying the location of the sample site. Half of the reach length was surveyed upstream and half downstream of the center point. Stream inventory surveys followed CDFG protocols (Flosi et al. 1998) sampling 100% of the selected reach.

CDFG fisheries biologist performed fish data collection using backpack electrofishers to determine presence of salmonid species. At least one pool, run, and riffle were electrofished from each sampling reach. Additionally, tributaries that were recently sampled by Humboldt State University students were not electrofished to minimize stress to fish and not to impact ongoing studies.

## Analytic Tools and Interdisciplinary Synthesis

### Integrated Analysis Tables

The multi-discipline team constructed a series of subject specific data tables, referred to as Integrated Analysis (IA) tables, to track the history and status of watershed processes. Through the use of IA tables the multidisciplinary data were synthesized, and the information used to respond to the six guiding assessment questions. The IA process also helped to identify and explain current watershed conditions. These integrated analyses are presented at both basin and subbasin levels. Land use and vegetation analyses have been further divided at the CalWater 2.2a Planning Watershed level.

The IA approach follows the down-slope movement of the five watershed products commonly delivered to streams by natural or human caused energy: water, sediment, organic woody debris, nutrients, and heat. Fundamental to these watershed processes and products are the underlying geology and geomorphology of the watershed. Geologic conditions determine, in large part, the landslide and sediment production potential of the terrain. Geologic processes are influenced in varying degrees by the vegetative community, which is often linked to human activities across the landscape. Current watershed conditions combine with natural events like fire, flood, and earthquakes to affect the fluvial geomorphology and water quality in the stream reaches of a watershed. Finally, the effects of these combined processes are expressed in stream habitats encountered by the organisms of the aquatic riparian community, including salmon and steelhead.

Links between cause and effect are complicated by spatial and temporal dynamics of watershed processes. A direct link between cause and effect may be the resulting increase in stream temperature in response to removal of shade canopy over a stream. Less clear examples include aggradation of the streambed and the series of related impacts to stream habitat. For example, which upstream sediment sources yielded the sediment, when did the sediment delivery occur and why, and can they be controlled or prevented. Many components act together at various spatial and temporal scales to elicit the effect or condition expressed by a watershed, stream, or a fish population. Thus cumulative effects form a variety of environmental and socio-economic factors also must be considered for this analysis.

### Ecological Management Decision Support System

The assessment program selected the Ecosystem Management Decision Support system software to help synthesize information on watershed and stream conditions. The EMDS system was developed at the USDA-Forest Service, Pacific Northwest Research Station (Reynolds 1999). It employs a linked set of software that includes MS Excel, NetWeaver, the Ecological Management Decision Support (EMDS) ArcView Extension, and ArcView™. The NetWeaver software, developed at Pennsylvania State University, helps scientists model linked frameworks of various environmental factors called knowledge base networks (Reynolds et al. 1996).

These networks specify how various environmental factors will be incorporated into an overall stream or watershed assessment. The networks resemble branching tree-like flow charts, graphically show the assessment's logic and assumptions, and are used in conjunction with spatial data stored in a Geographic Information System (GIS) to perform assessments and render the results into maps. This combination of software is currently being used for watershed and stream reach assessment on federal lands included in the Northwest Forest Plan (NWFP).

Forest Plan scientists constructed knowledge base models to identify and evaluate environmental factors (e.g. watershed geology, land use impacts, water quality, stream sediment loading, stream temperature, etc.) that shape anadromous salmonid habitat. Using this adaptive model structure, EMDS evaluated available NWFP watershed data to provide insight into stream and watershed conditions in relationship to target conditions known to be favorable to salmonids.

### **Development of the North Coast California EMDS Model**

Staff began development of EMDS knowledge base models with a three-day workshop in June of 2001 organized by the University of California, Berkeley. In addition to the assessment program staff, model developer Dr. Keith Reynolds and several outside scientists also participated. As a starting point, analysts used an EMDS knowledge base model developed by the Northwest Forest Plan for use in coastal Oregon. Based upon the workshop, subsequent discussions among staff and other scientists, examination of the literature, and consideration of localized California conditions, the assessment team scientists then developed preliminary versions of the EMDS models.

### **The Knowledge Base Network**

For California's north coast watersheds, the assessment team originally constructed two knowledge base networks: 1) The Stream Reach Condition Model; and 2) The Watershed Condition Model. These models were reviewed in April 2002 by an independent nine-member science panel, which provided a number of suggestions for model improvements. According to their suggestions, the team revised the two original models and added three others focused on the analysis of specific components of instream and watershed conditions that affect salmonids:

- **The Stream Reach Condition model** addresses conditions for salmon on individual stream reaches and is largely based on data collected using CDFG stream survey protocols found in the California Salmonid Stream Habitat Restoration Manual, (Flosi et al. 1998);
- **The Sediment Production Risk model** evaluates the magnitudes of the various sediment sources in the basin according to whether they are natural or management related;
- **The Water Quality model** has not yet been developed, but will offer a means of assessing characteristics of instream water (flow and temperature) in relation to fish;
- **The Fish Habitat Quality model** has not yet been developed, but will incorporate the Stream Reach model results in combination with data on accessibility to spawning fish and a synoptic view of the condition of riparian vegetation for shade and large woody debris;
- **The Fish Food Availability model** has not yet been developed, but will evaluate the watershed based upon conditions for producing food sources for anadromous salmonids.

In creating these EMDS models, the team used what is termed a tiered, top-down approach. For example, the Stream Reach Condition model (Figure II- 2) tested the truth of the proposition: *The overall condition of the stream reach is suitable for maintaining healthy populations of native Chinook, coho, and steelhead trout.* A knowledge base network was then designed to evaluate the truth of that proposition, based upon existing data from each stream reach. The model design and contents reflected the specific data and information analysts believed were needed, and the manner in which they should be combined, to test the proposition.

In evaluating stream reach conditions for salmonids, the model uses data from several environmental factors. The first branching tier of the knowledge base network shows the data based summary nodes on: 1) in-channel condition; 2) stream flow; 3) riparian vegetation and; 4) water temperature. These nodes are combined into a single value to test the validity of the stream reach condition suitability proposition. In turn, each of the four summary branch node's values is formed from the combination of its more basic data components. The process is repeated until the knowledge base network incorporates all information believed to be important to the evaluation.

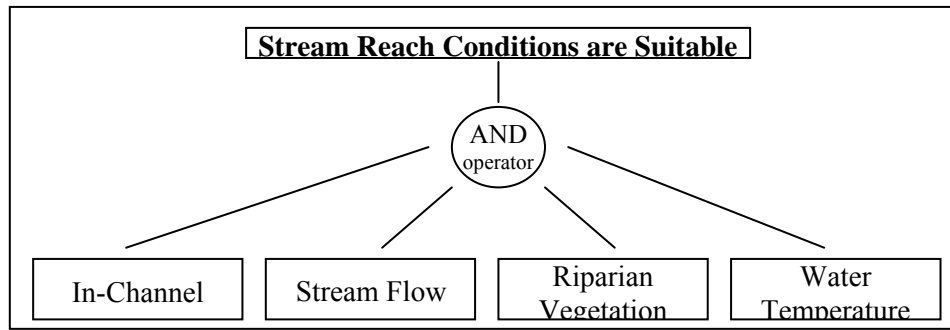


Figure II- 2. Tier one of the EMDS stream reach knowledge base network.

In Figure II- 3, the AND operator indicates a decision node that means that the lowest, most limiting value of the four general factors determined by the model will be passed on to indicate the potential of the stream reach to sustain salmonid populations. In that sense, the model mimics nature. For example, if summertime low flow is reduced to a level deleterious to fish survival or well being, regardless of a favorable temperature regime, instream habitat, and/or riparian conditions, the overall stream condition is not suitable to support salmonids.

Although model construction is typically done top-down, models are run in EMDS from the bottom up. That is, stream reach data are usually entered at the lowest and most detailed level of the several branches of the network tree (the leaves). The data from the leaves are combined progressively with other related attribute information as the analysis proceeds up the network. Decision nodes are intersections in the model networks where two or more factors are combined before passing the resultant information on up the network.

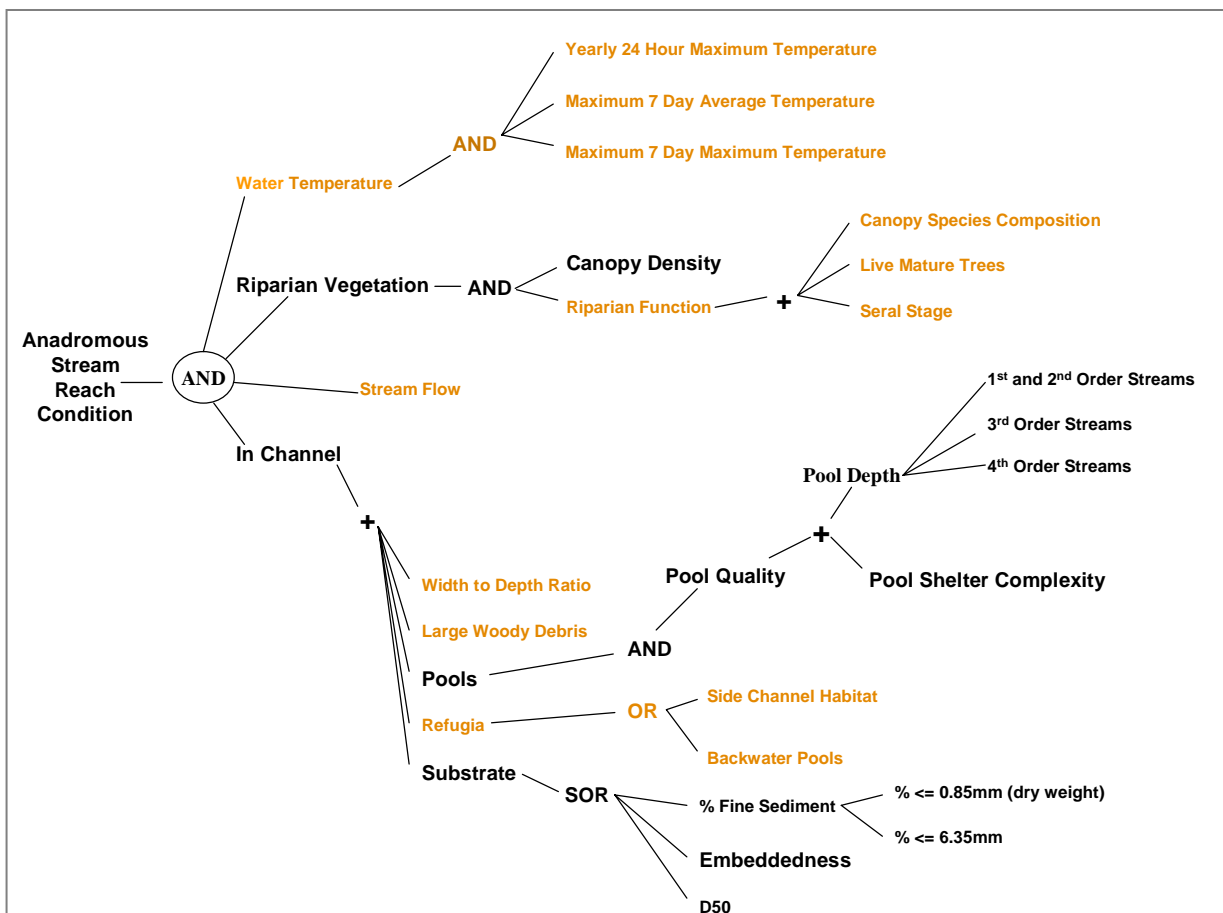


Figure II- 3. Graphic representation of the Stream Reach Condition model.

Habitat factors populated with data in the Albion assessment model are shown in black. Other habitat factors considered important for stream habitat condition evaluation, but data limited in the Albion assessment, are included in orange.

EMDS models assess the degree of truth (or falsehood) of each model proposition. Each proposition is evaluated in reference to simple graphs called reference curves that determine its degree of truth/falsehood, according to the data's implications for salmon. Figure II- 4 shows an example reference curve for the proposition *stream temperature is suitable for salmon*. The horizontal axis shows temperature in degrees Fahrenheit, while the vertical axis is labeled Truth Value and ranges from values of +1 to -1. The upper horizontal line arrays the fully suitable temperatures from 50-60°F (+1). The fully unsuitable temperatures are arrayed at the bottom (-1). Those in between are ramped between the fully suitable and fully unsuitable ranges and are rated accordingly. A similar numeric relation is determined for all attributes evaluated with reference curves in the EMDS models.

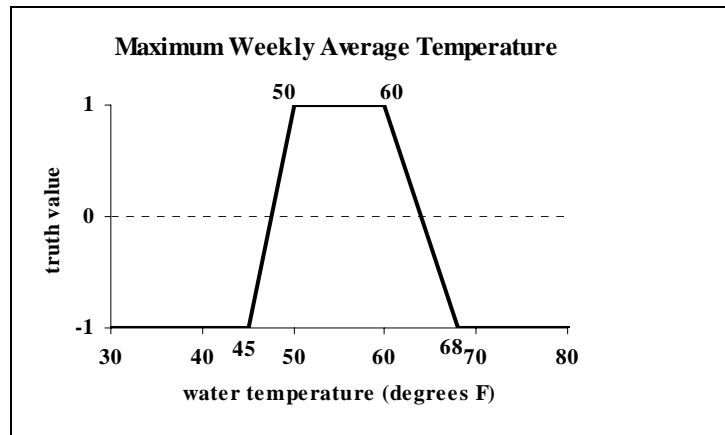


Figure II- 4. EMDS reference curve for stream temperature.

EMDS uses this type of reference curve in conjunction with data specific to a stream reach. This example reference curve evaluates the proposition that the stream's water temperature is suitable for salmonids. Break points on the curve can be set for specific species, life stage, or season of the year. Curves are dependent upon the availability of data in order to be included in an analysis.

For each evaluated proposition in the EMDS model network, the result is a number between -1 and +1. The number relates to the degree to which the data support or refute the proposition. In all cases a value of +1 means that the proposition is completely true, and -1 implies that it is completely false, while in-between values indicate degrees of truth (i.e. values approaching +1 being closer to true and those approaching -1 converging on completely untrue). A zero value means that the proposition cannot be evaluated based upon the data available. Breakpoints occur where the slope of the reference curve changes. For example, in Figure II- 4 breakpoints occur at 45, 50, 60, and 68°F.

EMDS map legends use a seven-class system for depicting the truth-values. Values of +1 are classed as the highest suitability; values of -1 are classed as the lowest suitability; and values of 0 are undetermined. Between 0 and 1 are two classes which, although unlabeled in the legend, indicate intermediate values of better suitability (0 to 0.5; and 0.5 to 1). Symmetrically, between 0 and -1 are two similar classes which are intermediate values of worse suitability (0 to -0.5; and -0.5 to -1). These ranking values are assigned based upon condition findings in relationship to the criteria in the reference curves. Table II- 2 summarizes important EMDS Stream Reach Condition model information.

Table II- 2. Reference curve metrics for EMDS stream reach condition model.

Stream Reach Condition Factor	Definition and Reference Curve Metrics
<b>Aquatic / Riparian Conditions</b>	
Summer MWAT	Maximum 7-day average summer water temperature <45°F fully unsuitable, 50-60°F fully suitable, >68°F fully unsuitable. Water temperature was not included in current EMDS evaluation.
Riparian Function	Under development.
Canopy Density	Average percent of the thalweg within a stream reach influenced by tree canopy. <50% fully unsuitable, ≥85% fully suitable.
Seral Stage	Seral stage composition of near stream forest. Under development
Vegetation Type	Forest composition Under development.
Stream Flow	Under development.
<b>In-Channel Conditions</b>	
Pool Depth	Percent of stream reach with pools of a maximum depth of 2.5, 3, and 4 feet deep for first and second, third, and fourth order streams respectively. ≤20% fully unsuitable, 30 – 55% fully suitable, ≥90% fully unsuitable.
Pool Shelter Complexity	Relative measure of quantity and composition of large woody debris, root wads, boulders, undercut banks, bubble curtain, overhanging and instream vegetation. ≤30 fully unsuitable, ≥100 - 300 fully suitable.
Pool Frequency	Percent of pools by length in a stream reach. Under development.
Substrate Embeddedness	Pool tail embeddedness is a measure of the percent of small cobbles (2.5" to 5" in diameter) buried in fine sediments. EMDS calculates categorical embeddedness data to produce evaluation scores between –1 and +1. The proposition is fully true if evaluation scores are 0.8 or greater and -0.8 evaluate to fully false
Percent Fines in Substrate <0.85mm (dry weight)	Percent of fine sized particles <0.85 mm collected from McNeil type samples. <10% fully suitable, >15% fully unsuitable. There was not enough of percent fines data to use percent fines in EMDS evaluations.
Percent Fines in Substrate < 6.4 mm	Percent of fine sized particles < 6.4 mm collected from McNeil type samples. <15% fully suitable, >30% fully unsuitable. There was not enough of percent fines data to use percent fines in EMDS evaluations.
Large Woody Debris (LWD)	The reference values for frequency and volume is derived from Bilby and Ward (1989) and is dependent on channel size. See EMDS Appendix for details. Most watersheds do not have sufficient LWD surveys for use in EMDS.
Winter Refugia Habitat	Winter refugia is composed of backwater pools and side channel habitats and deep pools (>4 feet deep). Under development.
Pool to Riffle Ratio	Ratio of pools to riffle habitat units. Under development.
Width to Depth Ratio	Ratio of bankfull width to maximum depth at velocity crossovers. Under development.

### Advantages Offered by EMDS

EMDS offers a number of advantages for use in watershed assessments. Instead of being a hidden black box, each EMDS model has an open and intuitively understandable structure. The explicit nature of the model networks facilitates open communication among agency personnel and with the general public through simple graphics and easily understood flow diagrams. The models can be easily modified to incorporate alternative assumptions about the conditions of specific environmental factors (e.g., stream water temperature) required for suitable salmonid habitat.

Using ESRI Geographic Information System (GIS) software, EMDS maps the factors affecting fish habitat and shows how they vary across a basin. At this time, no other widely available package allows a knowledge base network to be linked directly with a geographic information system such as ESRI's ArcView™. This link is vital to the production of maps and other graphics reporting the watershed assessments. EMDS models also provide a consistent and repeatable approach to evaluating watershed conditions for fish. In addition, the maps from supporting levels of the model show the specific factors that, taken together, determine overall watershed conditions. This latter feature can help to identify what is most limiting to salmonids, and thus assist to prioritize restoration projects or modify land use practices.

Another feature of the system is the ease of running alternative scenarios. Scientists and others can test the sensitivity of the assessments to different assumptions about environmental factors and how they interact, through changing the knowledge-based network and breakpoints. What-if scenarios can be run by changing the shapes of reference curves, or by changing the way the data are combined and synthesized in the network.

NetWeaver/EMDS/ArcView tools can be applied to any scale of analysis, from reach specific to entire watersheds. The spatial scale can be set according to the spatial domain of the data selected for use and issue(s) of concern. Alternatively, through additional network development, smaller scale analyses (i.e., sub-watersheds) can be aggregated into a large hydrologic unit. With sufficient sampling and data, analyses can be done even upon single or multiple stream reaches.

### ***Limitations of the EMDS Model and Data Inputs***

While EMDS-based syntheses are important tools for watershed assessment, they do not by themselves yield a course of action for restoration and land management. EMDS results require interpretation, and how they are employed depends upon other important issues, such as social and economic concerns. In addition to the accuracy of the EMDS model constructed, the currency and completeness of the data available for a stream or watershed will strongly influence the degree of confidence in the results. External validation of the EMDS model using fish population data and other information should be done.

One disadvantage of linguistically based models such as EMDS is that they do not provide results with readily quantifiable levels of error. Therefore, EMDS should only be used as an indicative model, one that indicates the quality of watershed or instream conditions based on available data and the model structure. It is not intended to provide highly definitive answers, such as from a statistically based process model. It does provide a reasonable first approximation of conditions through a robust information synthesis approach; however, its outputs need to be considered and interpreted in the light of other information sources and the inherent limitations of the model and its data inputs. It also should be clearly noted that EMDS does not assess the marine phase of the salmonid life cycle, nor does it consider fishing pressures.

Program staff has identified some model or data elements needing attention and improvement in future iterations of EMDS. These currently include:

- Completion of quality control evaluation procedures;
- Adjust the model to better reflect differences between stream mainstems and tributaries, for example, the modification of canopy density standards for wide streams;
- Develop a suite of Stream Reach Model reference curves to better reflect the differences in expected conditions based upon various geographic watershed locations considering geology, vegetation, precipitation, and runoff patterns.

At this time, all of the recommendations made by our peer reviewers have not been implemented into the models. Additionally, EMDS results should be used as valuable but not necessarily definitive products, and their validation with other observations is necessary. The EMDS Appendix provides added detail concerning the system's structure and operations.

### ***Management Applications of Watershed Synthesis Results***

EMDS syntheses can be used at the basin scale- to show current watershed status. Maps depicting those factors that may be the largest impediments, as well as those areas where conditions are very good, can help guide protection and restoration strategies. The EMDS model can also help to assess the cost-effectiveness of different restoration strategies. By running sensitivity analyses on the effects of changing different habitat conditions, it can help decision makers determine how much effort is needed to significantly improve a given factor in a watershed and whether the investment is cost-effective.

At the project planning level, EMDS model results can help landowners, watershed groups, and others select the appropriate types of restoration projects and places (i.e., planning watersheds or larger) that can best contribute to recovery. Agencies will also use the information when reviewing projects on a watershed basis.

The main strength of using NetWeaver/EMDS/ArcView knowledge base software in performing limiting factors analysis is its flexibility, and through explicit logic, easily communicated graphics, and repeatable results, it can provide insights as to the relative importance of the constraints limiting salmonids in North Coast watersheds. Thus the results have utility to assess fish habitat conditions in watersheds and to help prioritize restoration

efforts. They also facilitate an improved understanding of the complex relationships among environmental factors, human activities, and overall habitat quality for native salmon and trout.

### ***Adaptive Application for EMDS and CDFG Stream Habitat Evaluations***

CDFG has developed habitat evaluation standards, or target values, to help assess the condition of anadromous salmonid habitat in California streams (Flosi et al. 1998). These standards are based upon data analyses of over 1500 tributary surveys, and considerable review of pertinent literature. The EMDS reference curves have similar standards. These have been adapted from CDFG, but following peer review and professional discussion, they have been modified slightly due to more detailed application in EMDS. As such, slight differences occur between values found in Flosi et al. (1998) and those used by EMDS. The reference curves developed for the EMDS are provided in the EMDS Appendix of this report.

Both habitat evaluation systems have similar but slightly different functions. Stream habitat standards developed by CDFG are used to identify habitat conditions and establish priorities among streams considered for improvement projects based upon standard CDFG tributary reports. The EMDS compares select components of the stream habitat survey data to reference curve values and expresses degrees of habitat suitability for fish on a sliding scale. In addition, the EMDS produces a combined estimate of overall stream condition by combining the results from several stream habitat components. In the fish habitat relationship section of this report, we utilize target values found in Flosi et al. (1998), field observations, and results from EMDS reference curve evaluations to help describe and evaluate stream habitat conditions.

Due to the wide range of geology, topography and diverse stream channel characteristics which occur within the North Coast region, there are streams that require more detailed interpretation and explanation of results than can be simply generated by EMDS suitability criteria or tributary survey target values.

For example, pools are an important habitat component and a useful stream attribute to measure. However, some small fish-bearing stream channels may not have the stream power to scour pools of the depth and frequency considered to be high value “primary” pools by CDFG target values, or to be fully suitable according to EMDS. Often, these shallow pool conditions are found in low gradient stream reaches in small watersheds that lack sufficient discharge to deeply scour the channel. They also can exist in moderate to steep gradient reaches with bedrock/boulder dominated substrate highly resistant to scour, which also can result in few deep pools.

Therefore, some streams may not have the inherent ability to attain conditions that meet the suitability criteria or target values for pool depth. These scenarios result in pool habitat conditions that are not considered highly suitable by either assessment standard. However, these streams may still be very important because of other desirable features that support valuable fishery resources. As such, they receive additional evaluation with our refugia rating system and expert professional judgment. Field validation of any modeling system’s results is a necessary component of watershed assessment and reporting.

### **Limiting Factors Analysis**

A main objective of NCWAP watershed assessment is to identify factors that limit production of anadromous salmonid populations in North Coast watersheds. This process is known as a limiting factors analysis (LFA). The limiting factors concept is based upon the assumption that eventually a population must be limited by the availability of necessary support resources (Hilborn and Walters 1992) or that a population’s potential may be constrained by an over abundance, deficiency, or absence of a watershed ecosystem component. Identifying stream habitat factors that limit or constrain anadromous salmonids is an important step towards setting priorities for habitat improvement projects and management strategies aimed at the recovery of declining fish stocks and protection of viable fish populations.

Although several factors have contributed to the decline of anadromous salmonid populations, habitat loss and modification are major determinants of their current status (FEMAT 1993). Our approach to a LFA integrates two habitat based methods to evaluate the status of key aspects of stream habitat that affect anadromous salmonid production- species life history diversity and the stream’s ability to support viable populations.

The first method uses priority ranking of habitat categories based on a CDFG team assessment of data collected during stream habitat inventories. The second method uses the EMDS to evaluate the suitability of key stream habitat components to support anadromous fish populations. These habitat-based methods assume that stream habitat quality and quantity play important roles in a watershed's ability to produce viable salmonid populations.

The LFA assumes that poor habitat quality and reduced quantities of favorable habitat impairs fish production. The program LFA is focused mainly on those physical habitat factors within freshwater and estuarine ecosystems that affect spawning and subsequent juvenile life history requirements during low flow seasons. Two general categories of factors or mechanisms limit salmonid populations:

- Density independent and
- Density dependent mechanisms.

Density independent mechanisms generally operate without regard to population density. These include factors related to habitat quality such as stream flow and water temperature or chemistry. In general, fish will die regardless of the population density if flow is inadequate, or water temperatures or chemistry reach lethal levels. Density dependant mechanisms generally operate according to population density and habitat carrying capacity. Competition for food, space, and shelter are examples of density dependant factors that affect growth and survival.

The program's approach considers these two types of habitat factors before prioritizing recommendations for habitat management strategies. Priority steps are given to preserving and increasing the amount of high quality (density independent) habitat in a cost effective manner. More details of the LFA are presented in the CDFG Appendix.

## Restoration Needs/Tributary Recommendations Analysis

CDFG inventoried 13 tributaries to the Albion River and the headwaters of the Albion from 1994 to 2003 using protocols in the *California Salmonid Stream Habitat Restoration Manual*. The tributaries and the headwaters of the Albion River surveyed were composed of 30 stream reaches, defined as Rosgen channel types. The stream inventories are a combination of several stream reach surveys: habitat typing, channel typing, biological assessments, and in some reaches LWD and riparian zone recruitment assessments. An experienced biologist and/or habitat specialist conducted QA/QC on field crews and collected data, performed data analysis, and determined general areas of habitat deficiency based upon the analysis and synthesis of information.

CDFG biologists selected and ranked recommendations for each of the inventoried streams, based upon the results of these standard CDFG habitat inventories, and updated the recommendations with the results of the stream reach condition EMDS and the refugia analysis (Table II- 3). It is important to understand that these selections are made from stream reach conditions that were observed at the times of the surveys and do not include upslope watershed observations other than those that could be made from the streambed. They also reflect a single point in time and do not anticipate future conditions. However, these general recommendation categories have proven to be useful as the basis for specific project development, and provide focus for on-the-ground project design and implementation. Bear in mind that stream and watershed conditions change over time and periodic survey updates and field verification are necessary if watershed improvement projects are being considered.

Table II- 3. List of tributary recommendations in stream tributary reports.

Recommendation	Explanation
Temp	Summer water temperatures were measured to be above optimum for salmon and steelhead
Pool	Pools are below CDFG target values in quantity and/or quality
Cover	Escape cover is below CDFG target values
Bank	Stream banks are failing and yielding fine sediment into the stream
Roads	Fine sediment is entering the stream from the road system
Canopy	Shade canopy is below CDFG target values
Spawning Gravel	Spawning gravel is deficient in quality and/or quantity
LDA	Large debris accumulations are retaining large amounts of gravel and could need modification
Livestock	There is evidence that stock are impacting the stream or riparian area and exclusion should be considered
Fish Passage	There are barriers to fish migration in the stream

In general, the recommendations that involve erosion and sediment reduction by treating roads and failing stream banks, and riparian and near stream vegetation improvements precede the instream recommendations in reaches that demonstrate disturbance levels associated with watersheds in current stress. Instream improvement recommendations are usually a high priority in streams that reflect watersheds in recovery or good health. Various project treatment recommendations can be made concurrently if watershed and stream conditions warrant.

Fish passage problems, especially in situations where favorable stream habitat reaches are being separated by a man-caused feature (e.g., culvert), are usually a treatment priority. Good examples of these are the recent and dramatically successful Humboldt County/CDFG culvert replacement projects in tributaries to Humboldt Bay. In these regards, the program's more general watershed scale upslope assessments can go a long way in helping determine the suitability of conducting instream improvements based upon watershed health. As such, there is an important relationship between the instream and upslope assessments.

Additional considerations must enter into the decision process before these general recommendations are further developed into improvement activities. In addition to watershed condition considerations as a context for these recommendations, there are certain logistic considerations that enter into a recommendation's subsequent ranking for project development. These can include work party access limitations based upon lack of private party trespass permission and/or physically difficult or impossible locations of the candidate work sites. Biological considerations are made based upon the propensity for benefit to multiple or single fishery stocks or species. Cost benefit and project feasibility are also factors in project selection for design and development.

## Salmonid Refugia

Establishment and maintenance of salmonid refugia areas containing high quality habitat and sustaining fish populations are activities vital to the conservation of our anadromous salmonid resources (Moyle and Yoshiyama 1992; Li et al. 1995; Reeves et al. 1995). Protecting these areas will prevent the loss of the remaining high quality salmon habitat and salmonid populations. Therefore, a refugia investigation project should focus on identifying areas found to have high salmonid productivity and diversity. Identified areas should then be carefully managed for the following benefits:

- Protection of refugia areas to avoid loss of the last best salmon habitat and populations. The focus should be on protection for areas with high productivity and diversity;
- Refugia area populations which may provide a source for re-colonization of salmonids in nearby watersheds that have experienced local extinctions, or are at risk of local extinction due to small populations;
- Refugia areas provide a hedge against the difficulty in restoring extensive, degraded habitat and recovering imperiled populations in a timely manner (Kaufmann et al. 1997).

The concept of refugia is based on the premise that patches of aquatic habitat provide habitat that retains the natural capacity and ecologic functions to support wild anadromous salmonids in such vital activities as spawning and rearing. Anadromous salmonids exhibit typical features of patchy populations; they exist in dynamic environments and have developed various dispersal strategies including juvenile movements, adult straying, and relative high fecundity for an animal that exhibits some degree of parental care through nest building (Reeves et al. 1995). Conservation of patchy populations requires conservation of several suitable habitat patches and maintaining passage corridors between them.

Potential refugia may exist in areas where the surrounding landscape is marginally suitable for salmonid production or altered to a point that stocks have shown dramatic population declines in traditional salmonid streams. If altered streams or watersheds recover their historic natural productivity, through either restoration efforts or natural processes, the abundant source populations from nearby refugia can potentially re-colonize these areas or help sustain existing salmonid populations in marginal habitat. Protection of refugia areas is noted as an essential component of conservation efforts to ensure long-term survival of viable stocks, and a critical element towards recovery of depressed populations (Sedell 1990; Moyle and Yoshiyama 1992; Frissell 1993, 2000).

Refugia habitat elements include the following:

- Areas that provide shelter or protection during times of danger or distress;
- Locations and areas of high quality habitat that support populations limited to fragments of their former geographic range;
- A center from which dispersion may take place to re-colonize areas after a watershed and/or sub-watershed level disturbance event and readjustment takes place.

### ***Spatial and Temporal Scales of Refugia***

These refugia concepts become more complex in the context of the wide range of spatial and temporal habitat required for viable salmonid populations. Habitat can provide refuge at many scales from a single fish to groups of them, and finally to breeding populations. For example, refugia habitat may range from a piece of wood that provides instream shelter for a single fish, or individual pools that provide cool water for several rearing juveniles during hot summer months, to watersheds where conditions support sustaining populations of salmonid species. Refugia also include areas where critical life stage functions such as migrations and spawning occur. Although fragmented areas of suitable habitat are important, their connectivity is necessary to sustain the fisheries. Today, watershed scale refugia are needed to recover and sustain aquatic species (Moyle and Sato 1991). For the purpose of this discussion, refugia are considered at the fish bearing tributary and subbasin scales. These scales of refugia are generally more resilient to the deleterious effects of landscape and riverine disturbances such as large floods, persistent droughts, and human activities than the smaller, habitat unit level scale (Sedell et al. 1990).

Standards for refugia conditions are based on reference curves from the literature and CDFG data collection at the regional scale. The program uses these values in its EMDS models and stream inventory, improvement recommendation process. Li et al. (1995) suggested three prioritized steps to use the refugia concept to conserve salmonid resources.

- Identify salmonid refugia and ensure they are protected;
- Identify potential habitats that can be rehabilitated quickly;
- Determine how to connect dispersal corridors to patches of adequate habitat.

### ***Refugia and Meta-population Concept***

The concept of anadromous salmonid meta-populations is important when discussing refugia. The classic metapopulation model proposed by Levins (1969) assumes the environment is divided into discrete patches of suitable habitat. These patches include streams or stream reaches that are inhabited by different breeding populations or sub-populations (Barnhart 1994; McElhany et al. 2000). A metapopulation consists of a group of sub-populations which are geographically located such that over time, there is likely genetic exchange between the sub-populations (Barnhart 1994). Metapopulations are characterized by 1) relatively isolated, segregated breeding populations in a patchy environment that are connected to some degree by migration between them, and 2) a dynamic relationship between extinction and re-colonization of habitat patches.

Anadromous salmonids fit nicely into the sub-population and metapopulation concept because they exhibit a strong homing behavior to natal streams forming sub-populations, and have a tendency to stray into new areas. The straying or movement into nearby areas results in genetic exchange between sub-populations or seeding of other areas where populations are at low levels. This seeding comes from abundant or source populations supported by high quality habitat patches which may be considered as refugia.

Habitat patches differ in suitability and population strength. In addition to the classic metapopulation model, other theoretical types of spatially structured populations have been proposed (Li et al. 1995; McElhany et al. 2000). For example, the core and satellite (Li et al. 1995) or island-mainland population (McElhany et al. 2000) model depicts a core or mainland population from which dispersal to satellites or islands results in smaller surrounding populations. Most straying occurs from the core or mainland to the satellites or islands. Satellite or island populations are more prone to extinction than the core or mainland populations (Li et al. 1995; McElhany

et al. 2000). Another model termed source-sink populations is similar to the core-satellite or mainland-island models, but straying is one way, only from the highly productive source towards the sink subpopulations. Sink populations are not self-sustaining and are highly dependant on migrants from the source population to survive (McElhany et al. 2000). Sink populations may inhabit typically marginal or unsuitable habitat, but when environmental conditions strongly favor salmonid production, sink population areas may serve as important sites to buffer populations from disturbance events (Li et al. 1995) and increase basin population strength. In addition to testing new areas for potential suitable habitat, the source-sink strategy adds to the diversity of behavior patterns salmonids have adapted to maintain or expand into a dynamic aquatic environment.

The metapopulation and other spatially structured population models are important to consider when identifying refugia because in dynamic habitats, the location of suitable habitat changes (McElhany et al. 2000) over the long term from natural disturbance regimes (Reeves et al. 1995) and over the short term by human activities. Satellite, island, and sink populations need to be considered in the refugia selection process because they are an integral component of the metapopulation concept. They also may become the source population or refugia areas of the future.

### ***Methods to Identify Refugia***

Currently there is no established methodology to designate refugia habitat for California's anadromous salmonids. This is mainly due to a lack of sufficient data describing fish populations, meta-populations and habitat conditions and productivity across large areas. This lack of information holds true for all study basins especially in terms of meta-population dynamics. Studies are needed to determine population growth rates and straying rates of salmonid populations and sub-populations to better utilize spatial population structure to identify refugia habitat.

Classification systems, sets of criteria and rating systems have been proposed to help identify refugia type habitat in north coast streams, particularly in Oregon and Washington (Moyle and Yoshiyama 1992; FEMAT 1993; Li et al. 1995; Frissell et al. 2000; Kisup County 2000). Upon review of these works, several common themes emerge. A main theme is that refugia are not limited to areas of pristine habitat. While ecologically intact areas serve as dispersal centers for stock maintenance and potential recovery of depressed sub-populations, lower quality habitat areas also play important roles in long-term salmonid metapopulation maintenance. These areas may be considered the islands, satellites, or sinks in the metapopulation concept. With implementation of ecosystem management strategies aimed at maintaining or restoring natural processes, some of these areas may improve in habitat quality, show an increase in fish numbers, and add to the metapopulation strength.

A second common theme is that over time within the landscape mosaic of habitat patches, good habitat areas will suffer impacts and become less productive, and wink out and other areas will recover and wink in. These processes can occur through either human caused or natural disturbances or succession to new ecological states. Regardless, it is important that a balance be maintained in this alternating, patchwork dynamic to ensure that adequate good quality habitat is available for viable anadromous salmonid populations (Reeves et al. 1995).

### ***NCWAP Approach to Identifying Refugia***

The program's interdisciplinary refugia identification team identified and characterized refugia habitat by using professional judgment and criteria developed for North Coast watersheds. The criteria used considered different values of watershed and stream ecosystem processes, the presence and status of fishery resources, habitat quality, water quality, and other factors that may affect refugia productivity. The refugia team encouraged other specialists with local knowledge to participate in the refugia identification and categorization process.

The team also used results from information processed by the programs EMDS at the stream reach and planning watershed/subbasin scales. Stream reach and watershed parameter evaluation scores were used to rank stream and watershed conditions based on collected field data. Stream reach scale parameters included pool shelter rating, pool depth, embeddedness, and canopy cover. Water temperature data were also used when available. The individual parameter scores identified which habitat factors currently support or limit fish production (see EMDS and limiting factors sections).

Professional judgment, analyzing field notes, local expert opinion, habitat inventory survey results, water quality data results, and EMDS scores determined potential locations of refugia. If a habitat component received a suitable ranking from the EMDS model, it was cross-referenced to the survey results from that particular stream and to field notes taken during that survey. The components identified as potential refugia were then ranked according to their suitability to encourage and support salmonid health.

When identifying anadromous salmonid refugia, the program team took into account that anadromous salmon have several non-substitutable habitat needs for their life cycle. A minimal list (NMFS 2000) includes:

- Adult migration pathways;
- Spawning and incubation habitat;
- Stream rearing habitat;
- Forage and migration pathways;
- Estuarine habitat.

The best refugia areas are large, meet all of these life history needs, and therefore provide complete functionality to salmonid populations. These large, intact systems are scarce today and smaller refugia areas that provide for only some of the requirements have become very important areas, but cannot sustain large numbers of fish. These must operate in concert with other fragmented habitat areas for life history support and refugia connectivity becomes very important for success. Therefore, the refugia team considered relatively small, tributary areas in terms of their ability to provide at least partial refuge values, yet contribute to the aggregated refugia of larger scale areas. Therefore, the team's analyses used the tributary scale as the fundamental refugia unit.

Tributary ratings were determined by combining the results of NCRQCB water quality results, EMDS results, and data in CDFG tributary reports by a multi-disciplinary, expert team of analysts. The various factors' ratings were combined to determine an overall tributary rating on a scale from high to low quality refugia. Tributary ratings were subsequently aggregated at the subbasin scale and expressed a general estimate of subbasin refugia conditions. Factors with limited or missing data were noted. In most cases there were data limitations on 1–3 factors. These were identified for further investigation and inclusion in future analysis.

The program has created a hierarchy of refugia categories that contain several general habitat conditions. This descriptive system is used to rank areas by applying results of the analyses of stream and watershed conditions described above and are used to determine the ecological integrity of the study area. A basic definition of biotic integrity is "the ability [of an ecosystem] to support and maintain a balanced, integrated, and functional organization comparable to that of the natural habitat of the region" (Karr and Dudley 1981).

The Report of the Panel on the Ecological Integrity of Canada's National Parks submitted this definition:

#### **A DEFINITION OF ECOLOGICAL INTEGRITY**

The Panel proposes the following definition of ecological integrity: "An ecosystem has integrity when it is deemed characteristic for its natural region, including the composition and abundance of native species and biological communities, rates of change and supporting processes." "In plain language, ecosystems have integrity when they have their native components (plants, animals and other organisms) and processes (such as growth and reproduction) intact."

## **Salmonid Refugia Categories and Criteria:**

### ***High Quality Habitat, High Quality Refugia***

- Maintains a high level of watershed ecological integrity (Frissell 2000);
- Contains the range and variability of environmental conditions necessary to maintain community and species diversity and supports natural salmonid production (Moyle and Yoshiyama 1992; Frissell 2000);
- Relatively undisturbed and intact riparian corridor;
- All age classes of historically native salmonids present in good numbers, and a viable population of an ESA listed salmonid species is supported (Li et al. 1995);
- Provides population seed sources for dispersion, gene flow and re-colonization of nearby habitats from straying local salmonids;
- Contains a high degree of protection from degradation of its native components.

### ***High Potential Refugia***

- Watershed ecological integrity is diminished but remains good (Frissell 2000);
- Instream habitat quality remains suitable for salmonid production and is in the early stages of recovery from past disturbance;
- Riparian corridor is disturbed, but remains in fair to good condition;
- All age classes of historically native salmonids are present including ESA listed species, although in diminished numbers;
- Salmonid populations are reduced from historic levels, but still are likely to provide straying individuals to neighboring streams;
- Currently is managed to protect natural resources and has resilience to degradation, which demonstrates a strong potential to become high quality refugia (Moyle and Yoshiyama 1992; Frissell 2000).

### ***Medium Potential Refugia***

- Watershed ecological integrity is degraded or fragmented (Frissell 2000);
- Components of instream habitat are degraded, but support some salmonid production;
- Riparian corridor components are somewhat disturbed and in degraded condition;
- Native anadromous salmonids are present, but in low densities; some life stages or year classes are missing or only occasionally represented;
- Relative low numbers of salmonids make significant straying unlikely;
- Current management or recent natural events have caused impacts, but if positive change in either or both occurs, responsive habitat improvements should occur.

### ***Low Quality Habitat, Low Potential Refugia***

- Watershed ecological integrity is impaired (Frissell 2000);
- Most components of instream habitat are highly impaired;
- Riparian corridor components are degraded;
- Salmonids are poorly represented at all life stages and year classes, but especially in older year classes;
- Low numbers of salmonids make significant straying very unlikely;

- Current management and / or natural events have significantly altered the naturally functioning ecosystem and major changes in either of both are needed to improve conditions.

***Other Related Refugia Component Categories:***

***Potential Future Refugia (Non-Anadromous)***

- Areas where habitat quality remains high but does not currently support anadromous salmonid populations;
- An area of high habitat quality, but anadromous fish passage is blocked by man made obstructions such as dams or poorly designed culverts at stream crossings etc.

***Critical Contributing Areas***

- Area contributes a critical ecological function needed by salmonids such as providing a migration corridor, conveying spawning gravels, or supplying high quality water (Li et al. 1995);
- Riparian areas, floodplains, and wetlands that are directly linked to streams (Huntington and Frissell 1997).

***Data Limited***

- Areas with insufficient data describing fish populations, habitat conditions, watershed conditions, or management practices.